RADIATION DAMAGE-ELECTRON IMPACT

NASA Research Grant NsG-371

by

F. A. White

D. E. Kraus

Rensselaer Polytechnic Institute
Department of Nuclear Engineering and Science
Troy, New York

Status Report
April, 1965

Continuation of Experimental Work

Reference is made to the previous status report dated October 1964 relating to (1) the invention of a coincidence scheme for detecting single electrons and ions, and (2) a time-of-flight spectrometer to complement the magnet-electrostatic analyzer. During this report period, some data was acquired using the Linac and this latter device, and is included in this review.

Secondary Emission Coincidence Scheme

This invention relates to a system for detecting single electrons, ions or neutral atoms. It makes possible a discrimination against usual source of "noise" such as unwanted thermionic electrons in photomultiplier tubes, and it permits the detection of a very small number of particles, even in high radiation environments. A formal patent disclosure has been titled "Secondary Emission Coincidence Scheme of High Sensitivity for the Detection of Single Electrons, Ions, and Other Particles". The disclosure was dated January 15, 1965, in a letter to Dr. Smull, by F. A. White, citing F. A. White and D. E. Kraus as co-inventors.

The basic scheme is made clear by reference to Figure 1. The coincidence multiplier is comprised of (1) a particle "converter" (2) an electron focusing system (3) two electron multipliers and (4) a coincidence circuit.

It is known that high gain electron multiplier can be employed to detect photons (with a photo-cathode to convert light to electrons) or single charged particles. An important limitation, however, is the fact that a few electrons are usually emitted from the first cathode or succeeding "dynodes" at room temperature. These "background" electrons limit the ultimate particle sensitivity that can be achieved. It is difficult, for example, to detect currents of less than one electronic charge per second (1.6×10^{-19} ampere) due to this and other factors. Furthermore, these devices have a marked increase in "background" current if these are utilized in radiation fields which produce secondary electrons on any or all the multiplier dynodes or electron amplifying surfaces.

In this invention, both of these limitations are substantially bypassed by causing an electron or positive ion to penetrate the "converter" rather than terminate its trajectory in a conventional multiplier detector. Consider a 500 A^o foil which is sufficiently thin so that an electron of a few thousand volts kinetic energy or a light ion, for example, Li-6, 0-16, Na-23 of $\sim$30 Kev) can penetrate this foil. The ion, if it penetrates the converter, will cause the emission of one or several secondary electrons from the front surface of the converter. It will also, however, give rise to the production of secondary electrons as it leaves the back surface of the converter, even if it emerges as a neutral atom rather than an ion. Providing only that the residual kinetic energy is sufficient to generate one or more secondary electrons, we now have the advantage of detecting <u>two</u> simultaneous bursts of secondary ejected electrons, generated from a <u>single</u> particle.

The converter thus generates two groups of secondary electrons of very low kinetic energy (a few electron volts). These groups of electrons, on opposite faces of the converter, can easily be focused by conventional electron optics onto the first cathode or dynode of high gain multipliers. Output pulses from both of these multipliers can be fed into a coincidence circuit which will trigger only when simultaneous signals arise in the multipliers.

The advantages of this scheme are significant for the detection of particles or groups of photons which can be caused to generate simultaneous secondary electrons on each side of such a "converter foil" or target. These include:

1. The detection of an exceedingly small number of events per unit time, and the freedom from thermionic "noise" over a greatly extended time interval. (For example, in "conventional" photomultiplier tubes a background or "dark" current of 10^{-18} amperes is considered good. With this coincidence scheme, an "effective" background current can be reduced by a factor of 10^5, to 10^{-23} ampere. This implies that suitable particles can be detected in the range of one event per hour.

2. Discrimination from spurious pulses generated from the secondary electronic production of the many dynodes of a single multiplier in a radiation environment. Shielding requirements can then be minimized or eliminated.

3. Directional discrimination.

4. Wide area collection.

5. Fast response - generally better than a fluorescent material used in a coincidence arrangement.

A prototype detector has been constructed and tested. Two models, in fact, have been built. The second operated successfully and was tested as follows:

1. <u>Electrons</u> - A current of approximately 1000 electrons per second ($\sim 10^{-16}$ ampere) was made to impinge upon a 500 A^o nickel "converter" and coincidence multiplier scheme. Pulses, coincident within 5×10^{-8} second were observed on both multipliers.

When observed with a fast oscilloscope, no random or thermonically emitted electrons were observed in coincidence. Figure 2 shows the approximate minimum energies required for primary electrons to penetrate several foil materials. At 3000 eV coincidence pulses were observed.

2. Positive ions - (presumably Li-6 and Li-7 atoms) were focused on the converter. At 30 Kev, coincident pulses were observed. Ion currents were approximately the same as electron currents in this test. A one to one correspondence was not observed, but it is believed that a thinner foil would have given better results because the heavy ions have a small range, and heavier atoms - Na-23, K-39, Cs-133 may have been impurity ions in the unresolved beam.

3. Gamma Rays - The device was tested by gamma rays from a Po-Be radioactive source, rated at 11.5 mr at one meter. At 10 centimeters from this source no coincident gammas were observed.

4. Photons - Photons, emitted randomly, from a hot filament, produced secondary electrons (and hence output pulses) from both multipliers. The photon intensity could not be estimated, but with high counting rates in either channel (~ 105/sec) no coincident output pulses were observed. Both this and Test #3 prove the performance of such a scheme against "background" events.

Slight modification of the principle of the invention makes possible detection of other radiations (neutrons, gamma rays, and alpha particles in the presence of high backgrounds. The converter foil would be replaced with material sensitive to these radiations (e.g. B^{10}, Li^7 for neutrons) sufficiently thin that the range of particles produced in this interaction would reach both converter surfaces.

More complex geometries would permit secondary electrons produced on the same side of the converter material, but having different initial directions of motion, to drift into opposite multiplier geometries.

Time-of-Flight Apparatus

The 3-meter time-of-flight path was completed and made operational. The orientation of this apparatus with respect to the Linac drift tube and mass spectrometer is shown in Figure 3. The most recent configuration for recoil ion detection is displayed in Figure 4. The necessity for this additional apparatus became clear from these considerations:

(1) The spread in energy of the electrons from the Linac was larger than anticipated, greatly reducing ion recoil atom transmission,

(2) Angular acceptance of the spectrometer for a large area source was smaller than original estimates, and

(3) Background problems have proven to be so severe that only low energy heavy atoms have been detected.

The time-of-flight leg was also deemed a prerequisite for making an accurate calibration of Linac beam energy, without which the parameters for the mass spectrometer could not be appropriately programmed. This auxiliary apparatus was affixed to the Linac with suitable valves, ion pumps, etc. (The length is $\sim$3.5 meters.)

In order to obtain a reasonable solid angle of acceptance for recoil atoms from a foil on the Linac drift tube, a completely new multiplier assembly was made. Figure 4 shows the arrangement which utilized a large 4½" diameter single-sided "converter" foil made of thin aluminum. Bench tests showed that at least 30% of all Cs-133 atoms having energies greater than 5 Kev should give rise to output pulses from the electron-multiplier. Focusing of the secondary electrons into the multiplier was achieved by using a Phillips 58 AUP type geometry designed for 5-inch diameter phototubes.

A tunnel-diode discriminator and transistor amplifier were also designed and constructed which operated successfully in the Linac target room.

Linac Operation and Data Acquisition

A large fraction of Linac operational time was expended unprofitably. It became clear that several facets of this investigation required individual detailed studies relating to ion optics, electron multiplier detector efficiencies, analyses of electron and recoil ion energy spread, etc. -- these, in addition to the usual hurdles of high vacuum plumbing and remote control monitoring of electronics.

A crucial difficulty, not envisioned in the design of this experiment, was that an exceedingly high radiation background persists in the Linac target area -- many tens of microseconds after the primary intense bremsstrahlung. This background is attributed to a reasonably large flux of slow neutrons which eventually give rise to capture gammas that generate spurious counts in the detector. This limitation (together with multiplier saturation promptly after Linac bursts), restricted significant testing to a search for recoil gold atoms from a thin gold foil. Recoil atoms of gold, even undegraded in energy, have transit times sufficiently long to at least observe some counts above the general background.

Reference is made to Figures 5, 6 and 7 as exemplary of the general data obtained and background radiation problems. It will be noted that all three graphs have data corresponding to 100,000 Linac bursts.

The data exhibited in Figures 5 and 6 was taken at an electron multiplier high-voltage of 6400 V, at which setting the detector discriminator setting is believed to respond efficiently to a single secondary electron spectrum from the converter foil. The data for aluminum of two thicknesses appear to indicate a component of background corresponding to times greater than 50 microseconds, that is proportional to the number of atoms in the electron beam. No mechanism for this component has been demonstrated.

The data of Figure 6 show a pulse spectrum in time slightly later than the time-of-flight for elastic recoils, and persists to times corresponding to gold ion energies of 300 eV. Such a spectrum might be produced by the surface flux of the ion cascade when weighted by the detector sensitivity as a function of energy.

Data taken at a multiplier high voltage of 5900 V where the single-electron spectrum, and hence the low energy ions are more strongly discriminated against, are shown in Figure 7. Here a large number of events occur before the arrival time of the undegraded elastic recoils. The indicated conjecture has no confirmation save the rough agreement with energies expected in such a process.

Publications and Reports

As stated above, a formal patent disclosure was made during this period titled "Secondary Emission Coincidence Scheme of High Sensitivity for the Detection of Single Electrons, Ions, and Other Particles" - co-inventors, Frederick A. White, and David E. Kraus. A technical paper titled "Secondary Emission Coincidence Scheme for the Detection of Single Electrons and Ions" by D. E. Kraus and F. A. White, was presented on May 18 at the Thirteenth Annual Conference on Mass Spectrometry and Allied Topics, St.Louis, Mo. (Sponsored by the ASTM Committee, E-14 on Mass Spectrometry.)

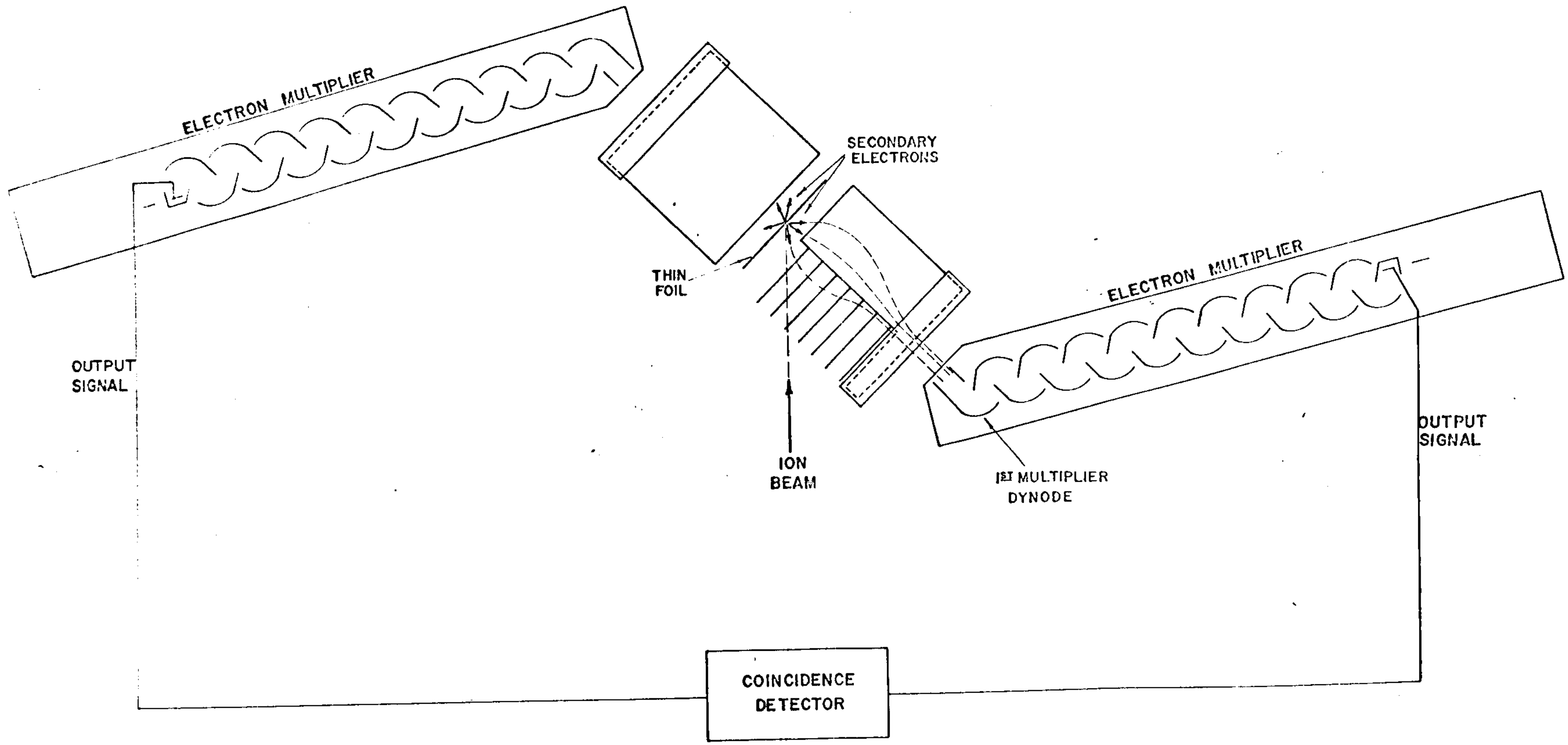

ELECTRON MULTIPLIER
SECONDARY ELECTRONS
THIN FOIL
ELECTRON MULTIPLIER
OUTPUT SIGNAL
ION BEAM
1st MULTIPLIER DYNODE
OUTPUT SIGNAL
COINCIDENCE DETECTOR

Figure 1

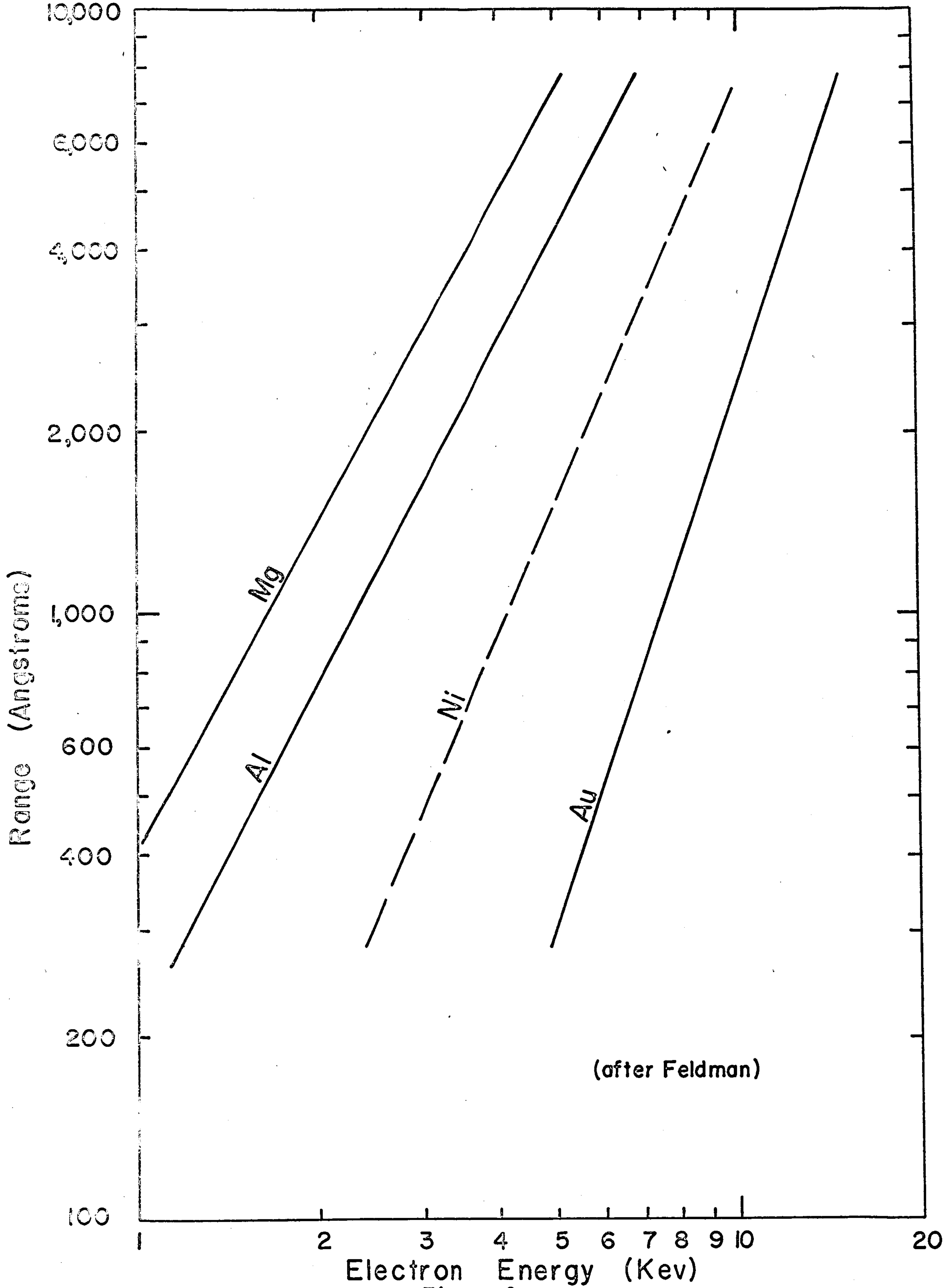

10,000
6,000
4,000
2,000
1,000
600
400
200
100
Range (Angstroms)
Mg
Al
Ni
Au
(after Feldman)
1
2
3
4
5
6
7
8
9
10
20
Electron Energy (Kev)

Figure 2

ION RECOIL
TIME-OF-FLIGHT LEG

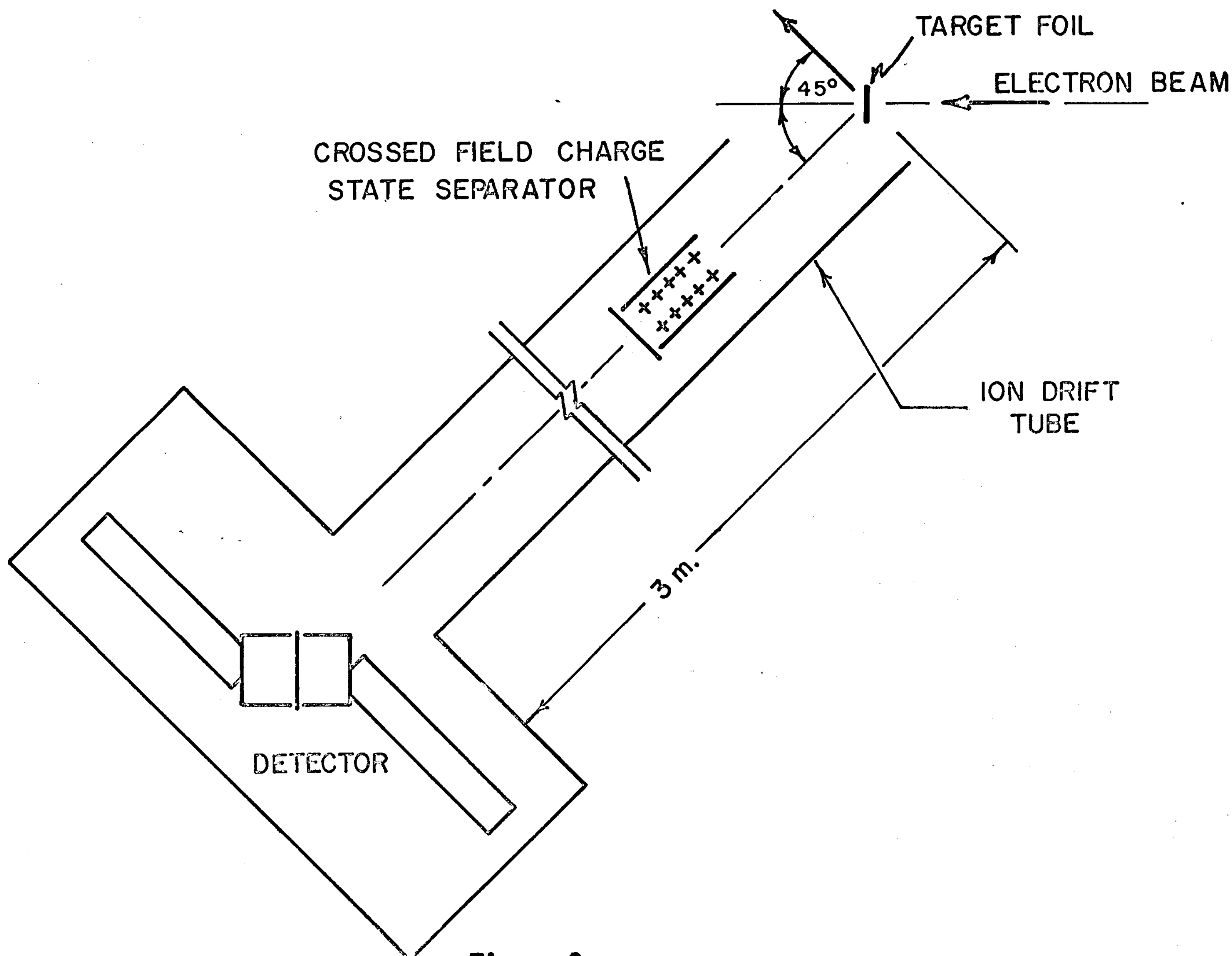


Figure 3

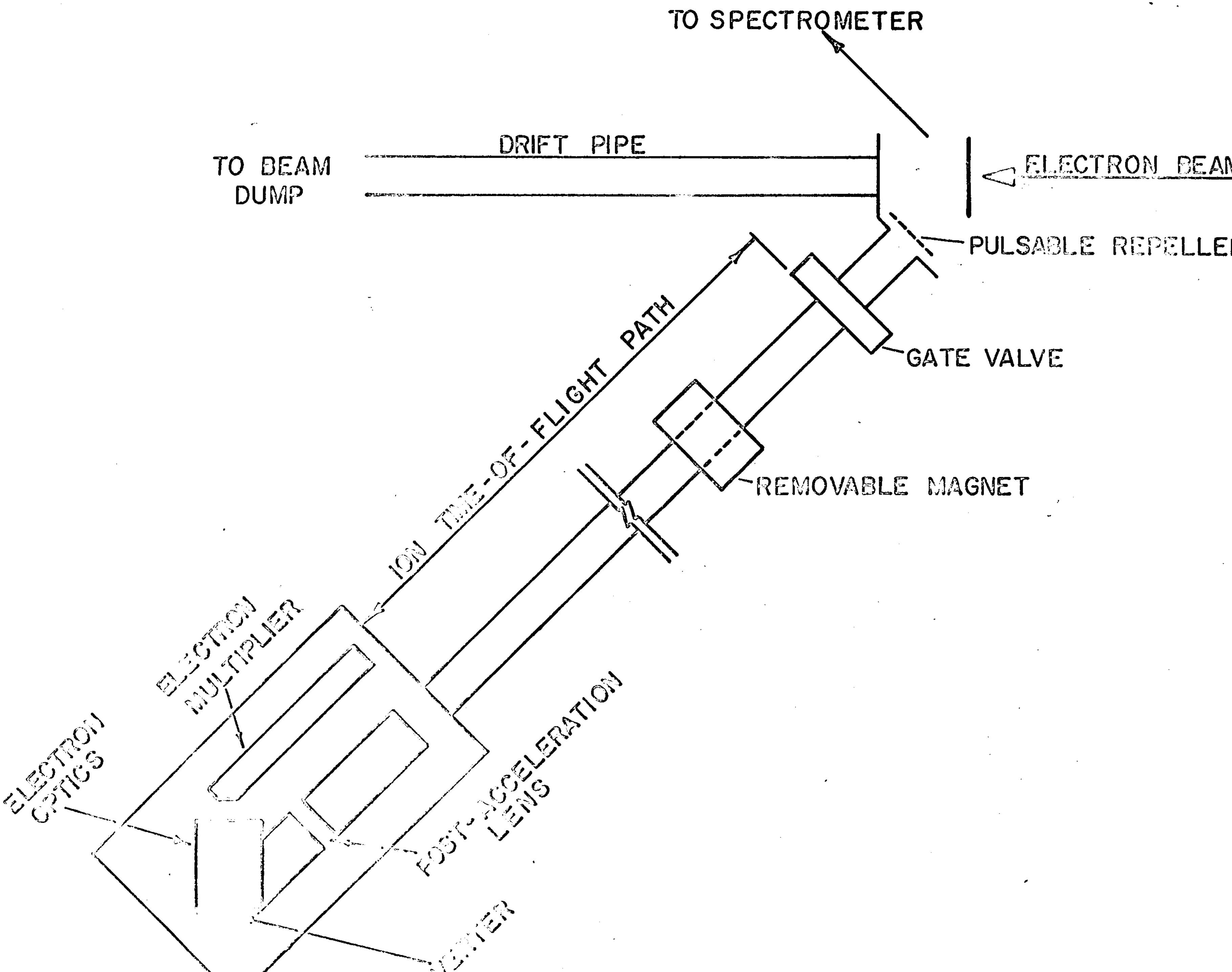

TO SPECTROMETER
DRIFT PIPE
TO BEAM DUMP
ELECTRON BEAM
PULSABLE REPELLER
GATE VALVE
REMOVABLE MAGNET
ION TIME-OF-FLIGHT PATH
ELECTRON MULTIPLIER
ELECTRON OPTICS
POST-ACCELERATION LENS

Figure 4

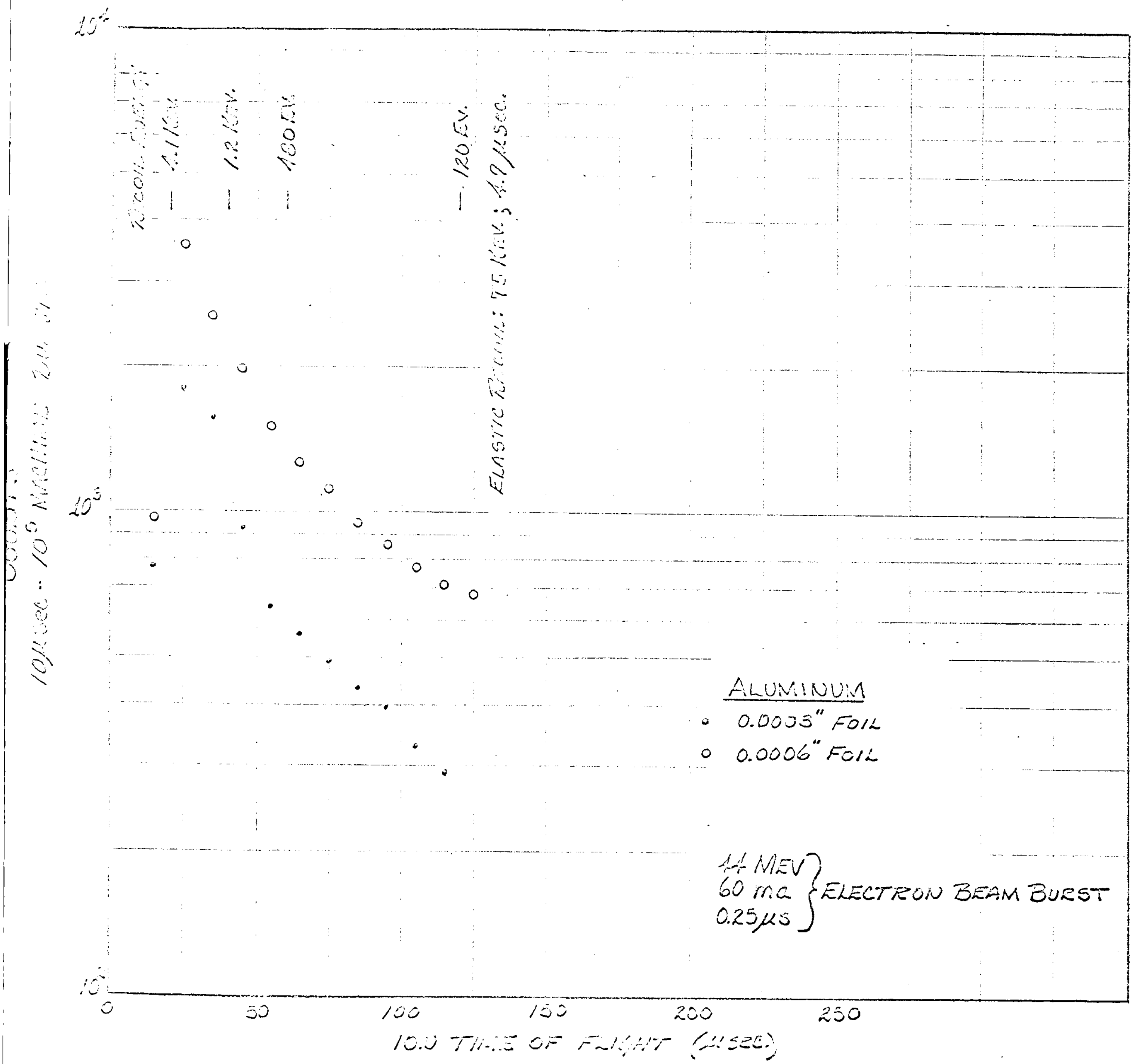
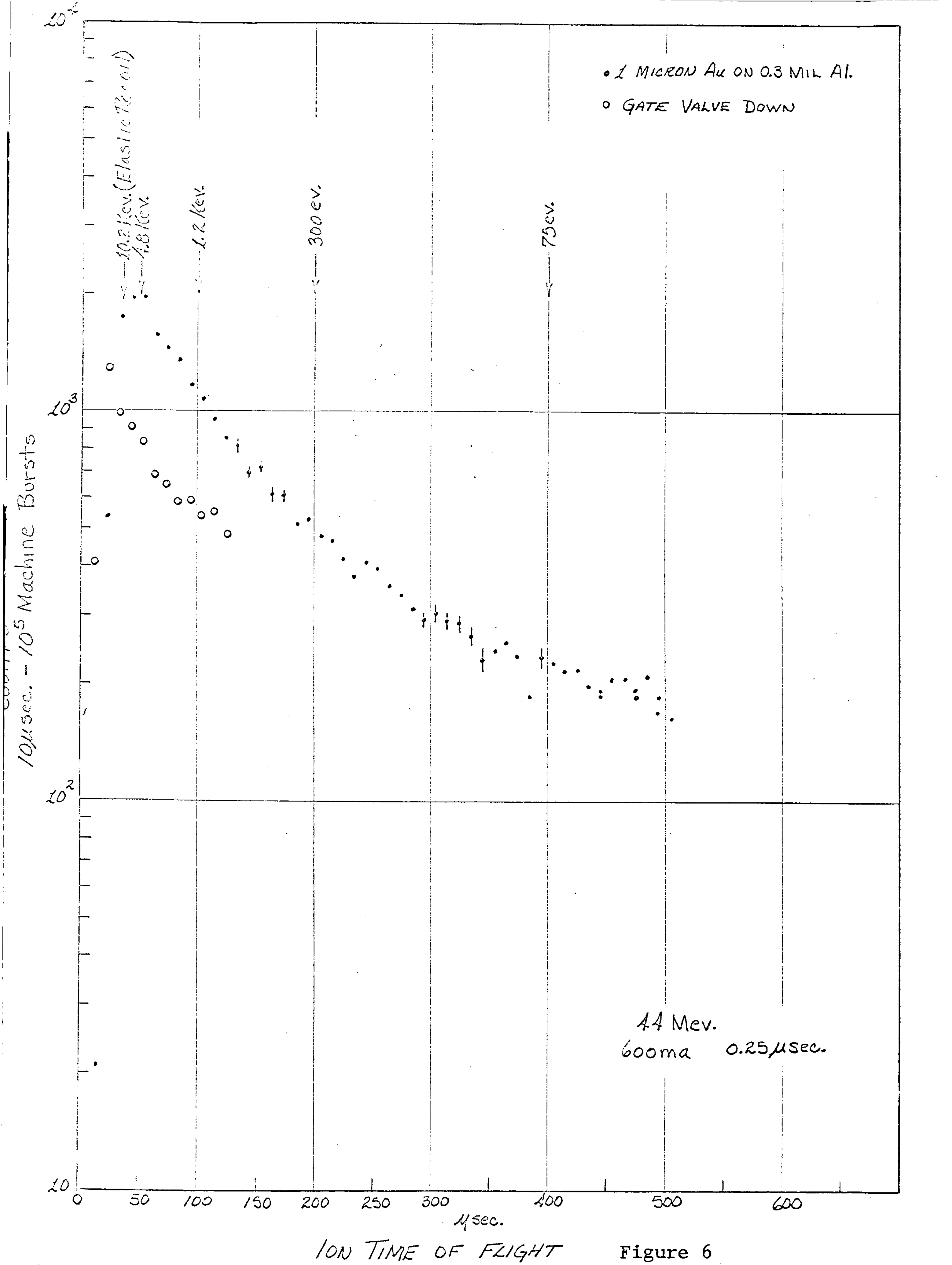
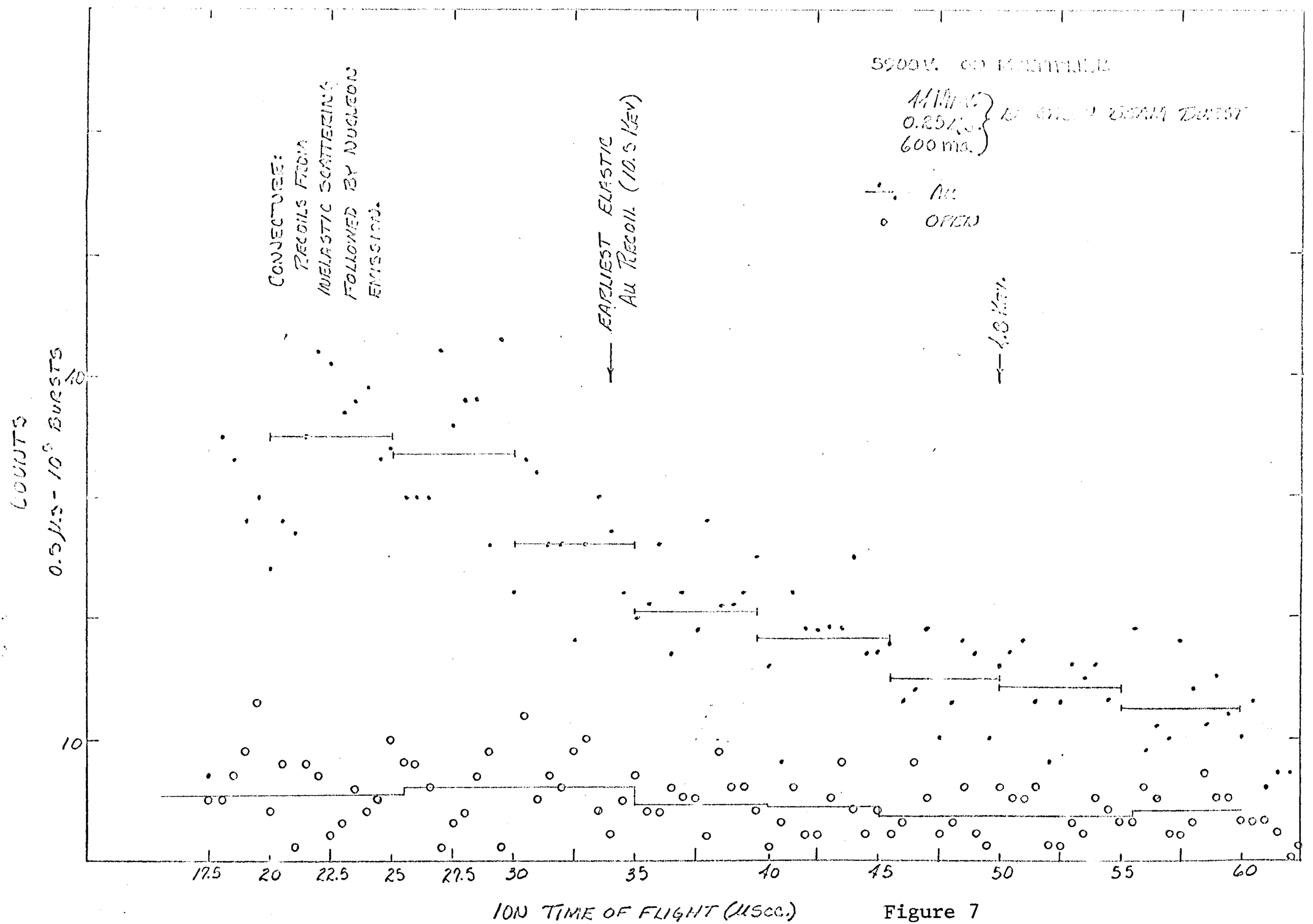

1.2 KEV.
180 EV.
120 EV.
ALUMINUM
0.0035" FOIL
0.0006" FOIL
44 MEV
60 ma
0.25 μs
ELECTRON BEAM BURST
0
50
100
150
200
250

Figure 5



• 1 MICRON Au ON 0.3 MIL Al.
○ GATE VALVE DOWN
10.2 kev. (Elastic Recoil)
4.8 kev.
1.2 kev.
300 ev.
75 ev.
44 Mev.
600 ma 0.25 μsec.
10μsec. - 10^5 Machine Bursts
10
10^2
10^3
0
50
100
150
200
250
300
400
500
600
μsec.
ION TIME OF FLIGHT

Figure 6



CONJECTURE:
RECOILS FROM
INELASTIC SCATTERING
FOLLOWED BY NUCLEON
EMISSION.
EARLIEST ELASTIC
AU RECOIL (10.5 KEV)
4.8 KEV.
600 ma.
AU
OPEN
COUNTS
10
17.5
20
22.5
25
27.5
30
35
40
45
50
55
60
ION TIME OF FLIGHT (μsec.)

Figure 7